Predictive Modelling of Color Projection Quality III

Surface Roughness Effects on Transparency Projection Efficiency

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Introduction

When a xerographic transparency is illuminated by an overhead projector (OHP), the transmitted light will be partially scattered (Fig. 1). The scattering occurs not only from inhomogeneities in the toner layer, but also from the refraction of light at the surface of a rough toner layer. The light will be loss if the local facet angle of the surface is too large.

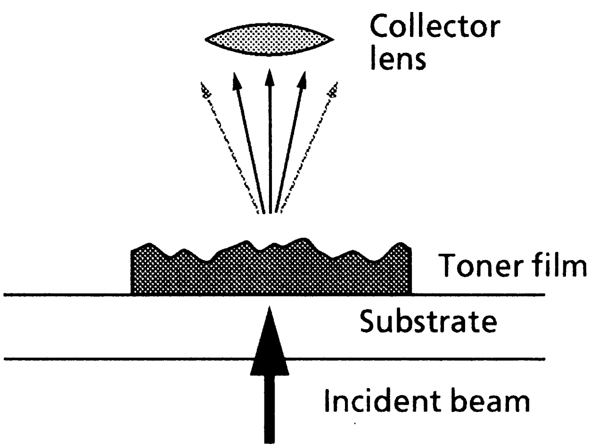


Figure 1. Schematic of transmission through a rough toner film. The dark thin arrows show light that will be collected by the lens.

We have used atomic force microscopy to quantify the height of fused toner surfaces. From the surface morphology, the spatial distribution of facet angles has been calculated. Fuser oil, which affects the agglomeration of the toners upon fusing, can give surfaces of the same roughness, but different facet angle distributions. Spatial maps and histograms of the facet angle can help identify the source of refraction. We find it is possible to generate smooth enough samples so that surface effects contribute insignificantly to projection efficiency.

Measurement Technique

Atomic force microscopy (AFM) is well-suited for determining the topography of toner films. We use the microscope in repulsive mode imaging,[1] where a surface is dragged under a sharp probe and the surface topography is inferred from the force acting on the probe (Fig. 2). It is a nonoptical technique and therefore not effected by variations in surface reflectivity, absorption, and other features which might mask the topography that is being measured. The lateral resolution is approximately 100 nm, which is the radius of curvature for the probes that we used.

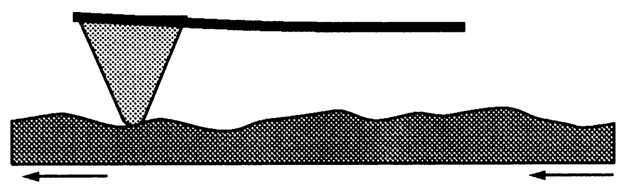


Figure 2. Schematic of AFM measurement. The probe is attached to a cantilever spring. The transparency sample is scanned under the probe. As the sample is scanned its height is adjusted to maintain a constant force against the probe.

A disadvantage of AFM is that only small regions of a surface can be examine at one time. Our particular scanner could only takes images of regions as large as 80×80 µm. If one looks at a small area which is not representative of the whole surface, then the results of a single measurement might fluctuate from the average for the entire surface. However, for the surfaces we examine we find 80 µm scans sufficient and statistically significant differences between different toner surfaces can be found with just a few measurements.

Extraction of the Facet Angle

Lipshitz, Bridger, and Derman have used an optical system which characterized topography to explore its relationship to image gloss.[2] They found the gloss is not completely described by the surface roughness. It is better characterized by the distribution of surface facet angles. The surface facet angle is the angle between the local surface normal and the normal to the surface as a whole. If the lateral scale of surface roughness variations is greater than the wavelength of light, then one can assume that light is locally refracted according to Snell's law and the facet angle completely describes the scattering of light by surface ripple.

of θ can be found for the four right triangles of different orientations from which a square can be divided.

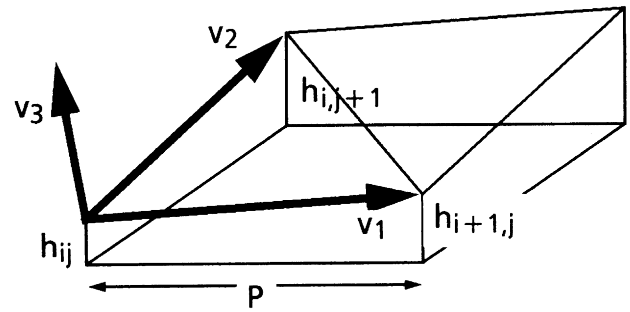


Figure 3. Illustration of how the local facet angle is determined.

An AFM measurements results in the collection of an image where each pixel gives the height of the surface at that point. A set of 3 neighboring points, as illustrated in Figure 3, define a plane. The cross product of the vectors v_1 and v_2 as illustrated in the figure give a vector v_3. The angle θ that this vector makes to the transparency surface is the facet angle. Specifically, the facet angle for a particular point on the surface is given by

$$\theta = \tan^{-1} \frac{\sqrt{(h_{i,j} - h_{i\pm 1,j})^2 + (i,j - i,j\pm 1)^2}}{P}$$

where $h_{i,j}$ is the height of the surface at the pixel indexed by *i,j*, and P is the distance between pixels. Four different sets of θ can be found for the four right triangles of different orientations from which a square can be divided.

Facet Angle Distribution for an Incompletely Fused Toner Film

In the fusing step of the xerographic process, the toners are melted and usually flow and agglomerate into a continuous film. The presence of oil on the toner surface alters its surface energy and inhibit the formation of continuous films. Two transparency samples were examined: one was made in the absence of fuser oil and gave a film of high projection efficiency, the other was made in the presence of fuser oil and gave a film of low projection efficiency.

Figure 4 shows AFM images of the two films. The gray level is proportional to the height of the surface. The difference in height between a black region and a white region is 1.9 μm.

Three different images were obtained for each sample. The RMS surface roughness for the sample without oil was 0.21 ± 0.04 μm, and for the oil containing sample was 0.21 ± 0.01 μm. Within the statistics of the measurements, these two films have the same surface roughness.

The facet angle was determined numerically. In Figure 5 a histogram of the facet angles for the different surfaces are displayed. The three different regions of the same surface have a slightly different histogram because only a small area of the surface is imaged. However, the variations between the regions is much smaller than the variation between samples. Therefore, even though AFM can image only small regions of the surface, this is enough to distinguish samples that will give poor and good projection efficiency.

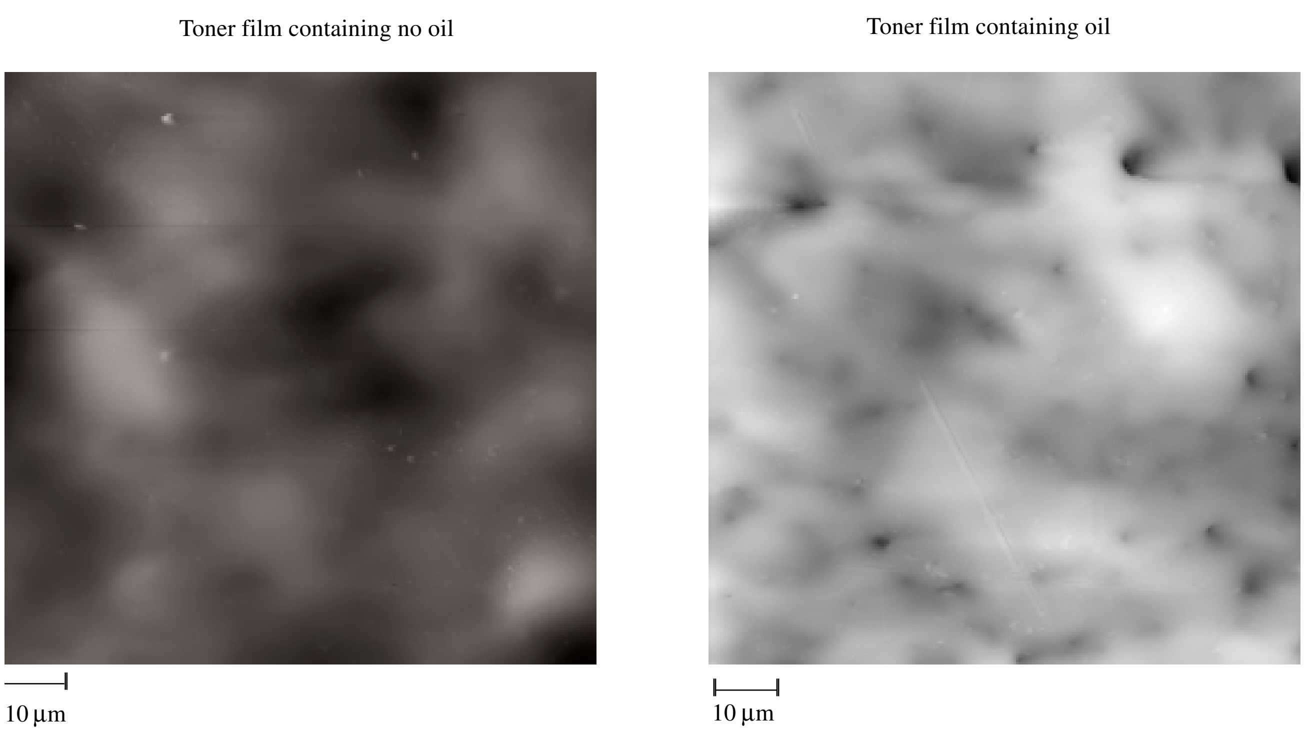


Figure 4. AFM morphology of two toner films. The left image was fused without fuser oil and has smoother features, while the right image was fused with fuser oil.

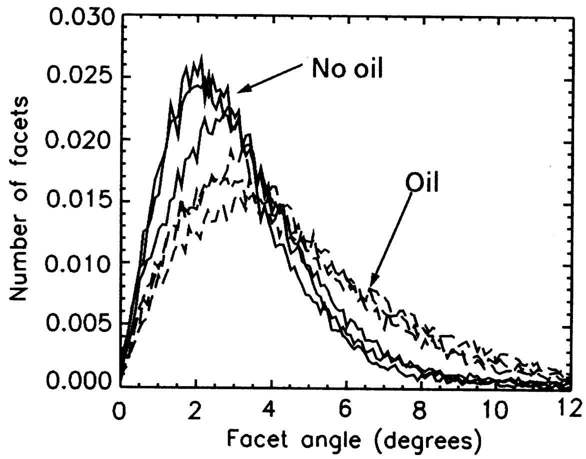
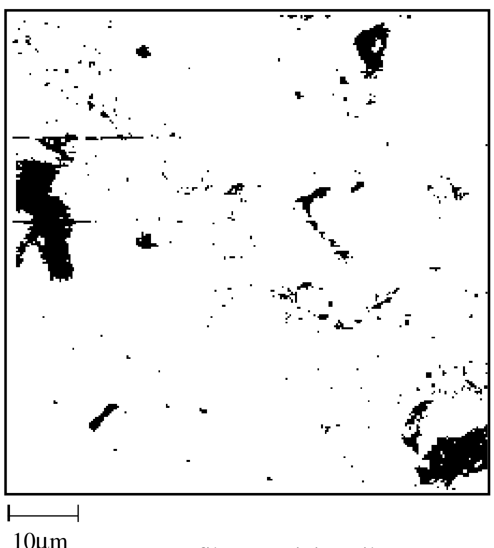


Figure 5. Facet angle distribution fortoner films fused without oil (solid lines) and with oil (dashed lines). The three liens are the histogram of images taken over three different areas of each film.

Toner film containing no oil



Toner film containing oil

Figure 6. Regions of the two toner films of Fig. 4 that will refract light away from the OHP lens. Black regions are those that will block light, and white regions will allow light to pass through.

Figure 6 shows the same images as Figure 4, but in these images, the pixel is turned black if its facet angle exceeds 5 degrees. This is the value which a resin of refractive index 1.6 will refract light away a OHP collector lens with a half-angle of 3°. In the film containing no oil, for which 90% of the light is collected, the large refraction comes predominately from 3 depressions in the film. In the oil containing film, which only 75% of the light is collected, the depressions are more numerous and are the source of the increased large refractions.

Surface Roughness of Films Used in Scattering Theory Experiments

A set of toner films of different developed masses per unit area used in part II of this series[3] were examined with AFM. Care with fusing was taken to achieve a flat toner surface. The RMS roughness of a set of 18 images was 0.028 µm, or over 7 times smoother than the films shown in Figure 4.

In Figure 7, the fraction of the facet angles greater than 5 degrees is plotted vs. area coverage. Although there is a lot of scatter in the data due to small areas being sampled, it appears that the surface roughness is independent of the toner layer thickness. The average fraction of facet angels greater than 5 degrees is 0.029. Examination of the images shows that a significant number of these are not depressions on the film, but bumps on the surface. These are likely to be pigment sitting on the surface, and are accounted for in the Mie scattering theory.[4] Therefore, quite a small amount of decreased projection efficiency is due to surface ripple and justifies its neglect in the comparison of projected color to Mie scattering theory.

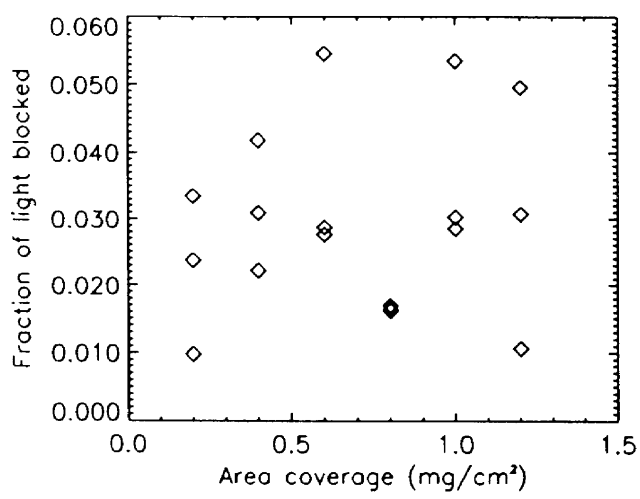


Figure 7. Surface roughness as a function of area coverage of a series of toner films of different developed masses per unit area.

Conclusion

AFM can be used to quantify the surface morphology that can degrade projection efficiency. However, it is possible to make films smooth enough so that surface roughness does not contribute significantly to the projection efficiency.

We thank Eddy Dalal for providing the transparency films used in this study.

References

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2. H. Lipshitz, M. Bridger, and G. Derman, “On the relationships between topography and gloss”, *Tappi J.*, **73**(10) 237, (1990).
3. E. N. Dalal, A. J. Paine, S. E. Blaszak, and I. D. Morrison, “Predictive Modelling of Color Projection Quality. II. Experimental Validation”, *Proc. IS&T 47th Annual Conf.*, Rochester, NY (1994); (see page 347, this publication).
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